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MBA PROFESSIONAL REPORT

ESTIMATING THE FULLY BURDENED COST OF SUPPLY IN A SELF-SUSTAINING SUPPLY CHAIN USING AN INPUT-OUTPUT MODEL

By: **Hasan Temel,**
Baris Ayrus, and
Mehmet Akif Aslan

December 2013

Advisors: **John Khawam**
Jay Simon

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13. ABSTRACT (maximum 200 words)

Armed forces of many countries conduct various operations both at home and worldwide. These operations are conducted not only in areas where procurement is viable, but also in areas where commodities consumed by the logistics activities are not locally available. Estimating and calculating the fully burdened cost of supply in such areas where commodities consumed by the logistics activities are not locally available has become a major research and study field.

This study focuses on the effects of change in vehicle fuel consumption rates on fully burdened cost of supplies in a self-sustaining supply chain and how the existence of demand at intermediate nodes affects the fully burdened cost of supplies. After modeling five different scenarios, the effects of changes in the size of convoy and delivery system were analyzed by comparing the results of each scenario. The results of this analysis show that small convoys in supply chains are more efficient than big convoys, and the fuel consumption rate of vehicles is so crucial that it should not be disregarded when estimating fully burdened cost of fuel.

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

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December 2013

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ABSTRACT

Armed forces of many countries conduct various operations both at home and worldwide. These operations are conducted not only in areas where procurement is viable, but also in areas where commodities consumed by the logistics activities are not locally available. Estimating and calculating the fully burdened cost of supply in such areas where commodities consumed by the logistics activities are not locally available has become a major research and study field.

This study focuses on the effects of change in vehicle fuel consumption rates on fully burdened cost of supplies in a self-sustaining supply chain and how the existence of demand at intermediate nodes affects the fully burdened cost of supplies. After modeling five different scenarios, the effects of changes in the size of convoy and delivery system were analyzed by comparing the results of each scenario. The results of this analysis show that small convoys in supply chains are more efficient than big convoys, and the fuel consumption rate of vehicles is so crucial that it should not be disregarded when estimating fully burdened cost of fuel.

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LIST OF ACRONYMS AND ABBREVIATIONS

AOA	analysis of alternatives
ASD OEPP	Assistant Secretary of Defense for Operational Energy Plans and Programs
COP	combat outpost
DAG	Defense Acquisition Guidebook
DAU	Defense Acquisition University
DESC	Defense Energy Support Center
DoD	Department of Defense
FBCE	fully burdened cost of energy
FBCF	fully burdened cost of fuel
FBCS	fully burdened cost of supply
M-ATV	MRAP all-terrain vehicle
MAS	MTVR armor system
MOB	main operating base
Mpg	miles per gallon
MRAP	mine-resistant, ambush-protected
MRE	meal, ready to eat
MTVR	medium tactical vehicle replacement
NGO	non-governmental organization
OUSD AT&L	Office of the Undersecretary of Defense for Acquisition, Technology and Logistics
SCM	supply chain management
SSSC	self-sustaining supply chain
USMC	United States Marine Corps
USN	United States Navy

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I. INTRODUCTION

A. SUPPLY CHAINS

Today it is viable for countries to transport their products all over the world. Improvements in technology and new trends in global trade have made all the borders closer, and enabled firms and countries to import and export what is needed. The concept of logistics is used frequently in this effort. Although logistics existed since prehistoric times, it has taken its place in literature as a new business term recently, and the definition and scope of logistics evolves continuously. Logistics which aims to meet customer needs has become a dynamic sector via globalization, advancing technology, and increasing consumer awareness.

The term logistics is commonly used in the military. In the military, logistics is defined as the armed forces' war preparation and all support services which enable them to remain alive in their operations. Especially during the World War II, logistics began to achieve wider recognition. Countries participating in World War II realized that it was not possible to win the war without proper logistics.

Although logistics is a term of military origin, it is also used today in commercial business. When logistics was first introduced into commercial business, it was generally used as a synonym for transportation. However, the scope and definition of logistics are wider than that. Logistics covers all of the processes between sourcing raw materials and distributing the manufactured products to the end user or customer. In this sense, the logistics process includes all procurement processes: ordering, purchasing, transporting, receiving, storage, insurance, maintenance, production, loading, unloading, packaging, inventory, distribution, and after-sales services.

1. Logistics Versus Supply Chain Management

The term *supply chain management* (SCM) gained considerable attention in the early 1980s. SCM also caused confusion, because the term was used interchangeably with logistics. These two terms are neither completely the same nor completely different. A number of supply chain experts have studied the relationship between logistics and

supply chain management. Some of them approached the issue from different perspectives. However, all of them agree that SCM covers logistics. Logistics is the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods, including services and related information, from the point of origin to the point of consumption for the purpose of conforming to customer requirements (Mangan et al., 2012), and this process continues within companies and at local levels. In SCM, the process continues not only within the company but also among other companies.

There are many definitions of SCM, but all of them are similar to each other and generally emphasize the same meaning. After examining 166 definitions of SCM, Stock & Boyer (2009), developed a consensus definition of SCM:

SCM is the management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow *of* materials, services, finances and information from the original producer to final customer with the benefits of adding value maximizing profitability through efficiencies and achieving customer satisfaction.

The companies involved are key factors in SCM. Raw material suppliers, intermediate component manufacturers, wholesalers, distributors, and retailers are directly involved in the supply chain. Some other companies are also involved indirectly. They provide services and make a contribution to supply chains by enabling the firms to provide goods where and when these goods are needed. They also provide efficient communication between buyers and sellers, and cheaper shipping inside the country or outside the country.

The integration of all systems in the supply chain provides comprehensive research and development, improved production methods, high quality, high profit margins, reliable transportation and storage facilities, a high level customer satisfaction, and effective usage of all resources.

Supply chain management is an incredibly complex undertaking involving cultural change among most or all the participants, investment and training in new software and communication systems, and a change or realignment of the competitive strategies employed among the participating firms. As competitive situations, product technology, and customers change, the priorities for the supply chain also must change, requiring supply chains to be ever more flexible to respond quickly to these changes (Wisner et al., 2005).

SCM grows in direct proportion with the markets for the supply chain. With improvements in technology and communication system, firms around the world have more capability to trade globally. Also, improvements and success in the practice of SCM have increased the scope of supply chains.

There are now many other supply chain models which are implemented in different kinds of logistics sectors. Response supply chains are developed to organize all logistics activities in natural disasters and lessen the pain of affected peoples. Sustainable supply chains are developed to use resources efficiently by a reuse, recycle, and return policy. Self-sustaining supply chains are developed to enable firms or systems to survive on their own; these supply chains carry all of the commodities which are not locally available to meet both their needs and the demands of the end user.

2. Self-Sustaining Supply Chain

Self-sustaining supply chains (SSSC) are becoming more relevant to most countries' defense ministries or departments as they proceed through the twenty-first century. In the last decade, due largely to pressures from various stakeholders, especially government regulators, community activists, non-governmental organizations (NGOs), and global competition, many companies have adopted a certain level of commitment to sustainability practices. Although the defense budget is generally decreasing, the armed forces have to maintain the same capabilities as in the past while using fewer resources. As a result self-sustainability becomes a key initiative for many countries, especially during recent economic crises.

The Supply Chain Network consists of three components, which are supply, demand, and flow. A Self- Sustaining Supply Chain network has the same three elements as well. But the difference between these two networks is the method of flow. Even though regular supply chain networks do not need to carry resources other than their own, self-sustaining supply chain networks have to carry all of the commodities which are not locally available to meet both their needs and responders' demands quickly at the same time. As understood from the last sentence, self-sustaining supply chains are more complicated and differentiated than both regular supply chain and sustainable supply chain networks by requiring that all resources consumed while transporting supplies to their destinations be provided via the network. Due to its complexity the cost of a self - sustaining supply chain is bigger than that of the normal chains. These types of networks are common for operations in undeveloped or disaster-impacted regions, and these requirements make the SSSC more complicated and expensive (Regnier et al., 2013). On the other hand, SSSC has to be agile to deliver, protect, and consume the supply in its network. In addition, it has to be persistent to meet the demand on the supply chain network while at the same time it is meeting its units' demand during the delivery time of commodities.

The SSSC has to have abilities to repair its network's damaged parts during its service time as well. Because of the current global economic crises and related fiscal issues, the budgets of most countries are shrinking, so they have to reduce their departments' budgets as well. All of these issues drew the attention of many nations to the topics of sustainability and self-sustainability more than ever before. During times of serious economic crisis, nations know that they must accomplish the same tasks with fewer resources. So, the term of self-sustainability makes good sense for the nations to take some precautions to decrease the effect of insufficiency. However, these steps are not as easy as is seen, due to the nature of SSSC. At the start of the SSSC, the network has some sort of goods. To become efficient, the amount of goods and the choice of goods on the network must be considered before the SSSC is initiated. This is because limited and small spaces are carrying more valuable goods. This consideration is important because if amount of goods which will be carried to their ultimate destination

and consumed during delivery by network are not correctly calculated, the consumers will not receive their goods correctly. At the same time, the network may encounter the danger of losing its life due to the lack of sufficient goods to support it.

The example of fuel in regard to the daily life of military forces can offer the best understanding of this topic. For instance, especially during their daily or weekly operations and drills, if the amount of fuel needed by both outpost troops and network vehicles is not calculated correctly, outpost troops will not be able to receive their needed fuel, and network vehicles may run out of fuel before reaching their destinations.

B. FULLY BURDENED COST

1. Fuel Consumption of DoD

The Department of Defense (DoD) is the largest U.S. government user of energy and the largest organizational user of petroleum in the world (Congressional Research Service, 2012). Since 2001 DoD's fuel costs have increased substantially and reached about $17.3 billion in FY2011. DoD consumes large amounts of energy while conducting various operations all around the world.

The amount of petroleum and money DoD spends for fueling jets, ships, and tactical vehicles, and powering domestic installations and forward operating bases, can be seen in Figure 1.

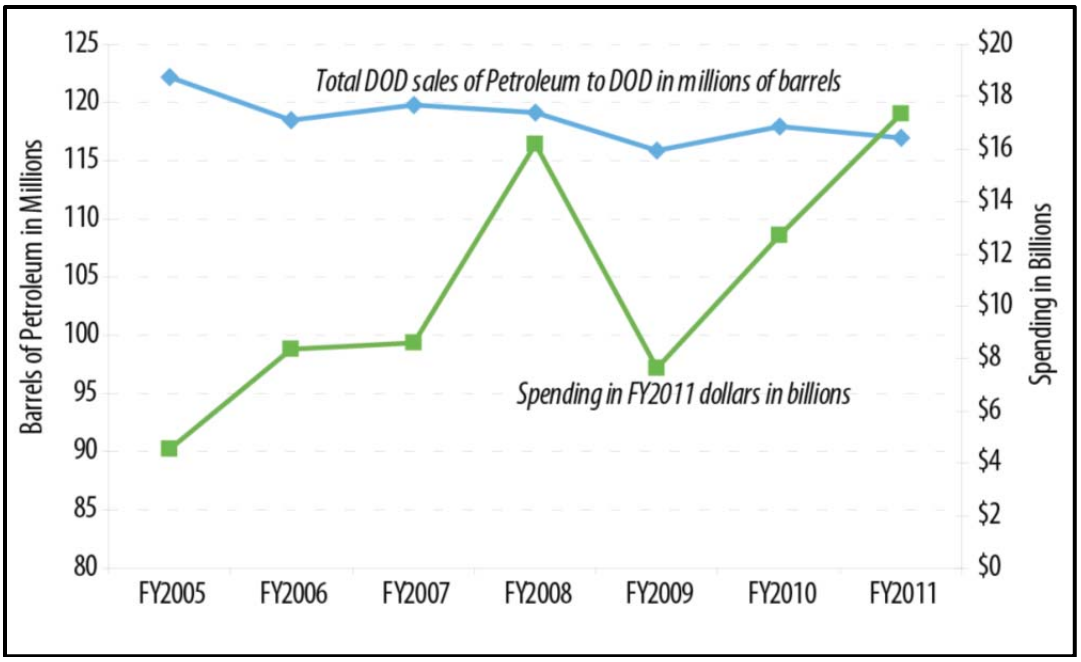

Figure 1. DoD petroleum spending and consumption
(from Congressional Research Service, 2012)

DoD's use of energy in FY2010 accounted for about 80% of the federal government's use of energy. In FY2011, DoD spent about $17.3 billion on petroleum-based fuels, accounting for about 2.5% of DoD's total outlays and about 6% of total operations and maintenance outlays for that year. Between FY2005 and FY2011, DoD's petroleum use decreased 4%. Over the same period, however, DoD's spending on petroleum rose 381% in real (i.e., inflation-adjusted) terms, from $4.5 billion in FY2005 (in FY2011 dollars) to about $17.3 billion in FY2011 (Congressional Research Service, 2012).

When the fuel use of DoD is divided by service, the Air Force is the largest consumer accounting for the 53% of total DoD fuel use. The Department of the Navy and Marine Corps use 28%, and the Army uses 18% of DoD's fuel (see Figure 2).

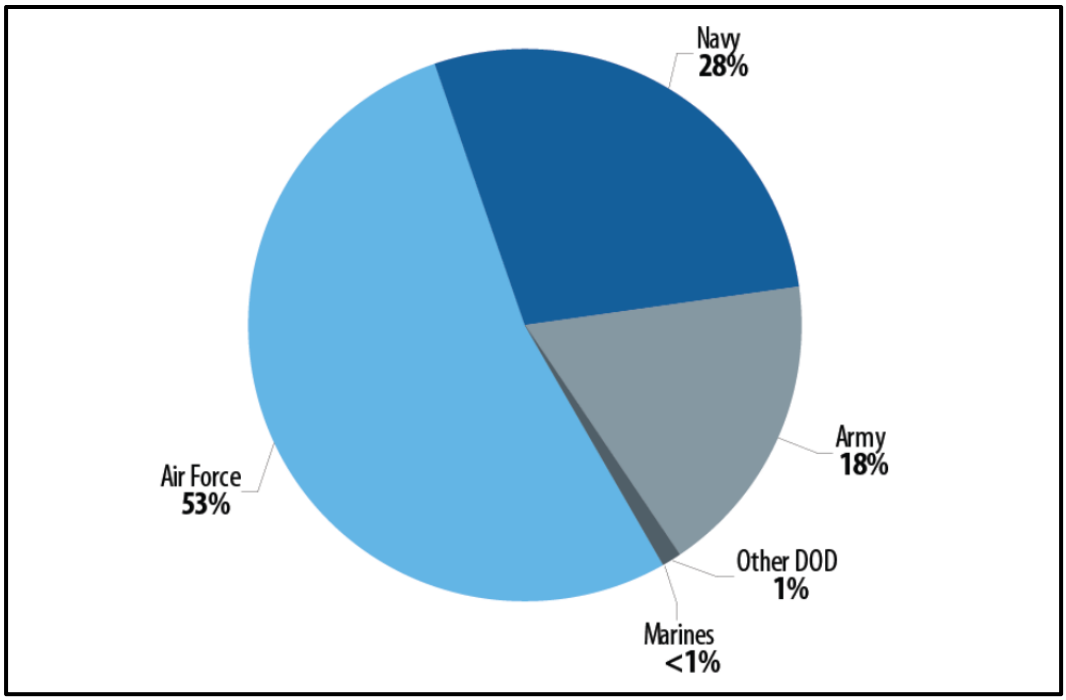

Figure 2. DoD petroleum use by service in FY2011
(from Congressional Research Service, 2012)

2. Operational Energy

DoD's energy use can be divided into two broad categories—operational energy and installation energy (Congressional Research Service, 2012). Operational energy is defined as the energy required for training, moving, and sustaining military forces and weapons platforms for military operations. The term includes energy used by tactical power systems and generators as well as weapons platforms (FY2012 National Defense Authorization Act, Public Law 112-81-December 31, 2011). Approximately 75% of the energy the Department consumed in 2009 was considered operational under this definition, while fixed installations accounted for the other 25%, largely for facilities and non-tactical vehicles as shown in Figure 3 (DoD, 2011).

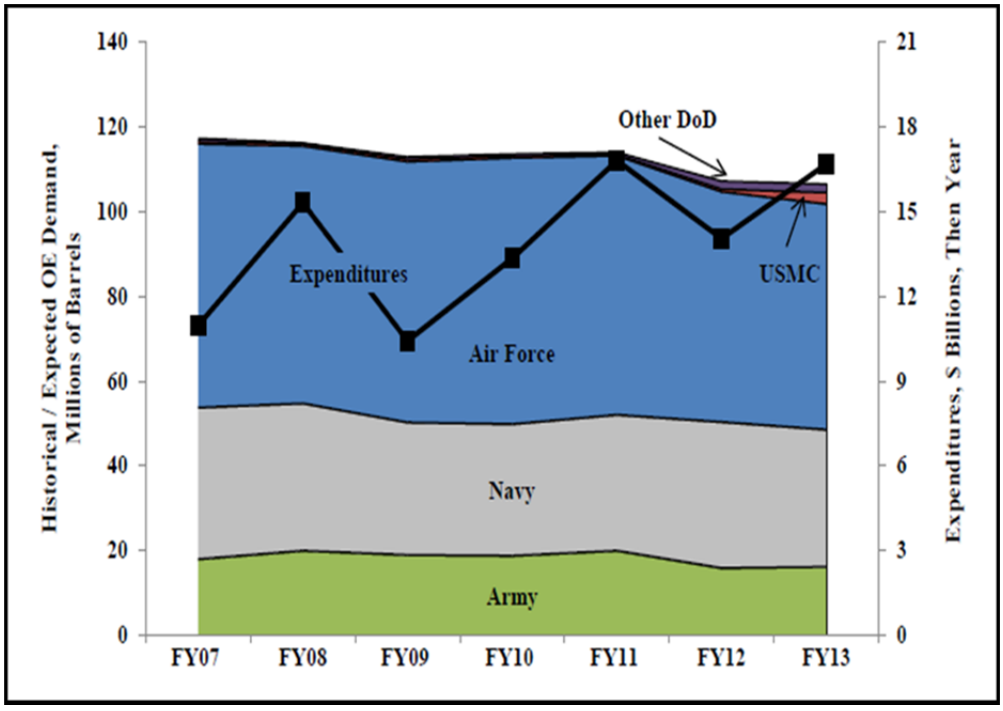

Figure 3. DoD operational energy demand, FY2007–FY2013 (from ASD (OEPP), 2013)

3. Fully Burdened Cost of Fuel

Fully Burdened Cost of Fuel (FBCF) is defined in Section 332(g) of the FY2009 Duncan Hunter National Defense Authorization Act as "the commodity price for fuel plus the total cost of all personnel and assets required to move and, when necessary, protect the fuel from the point at which the fuel is received from the commercial supplier to the point of use." Another definition of FBCF can be found in *The Defense Acquisition Guidebook* (DAG) as "the cost of fuel itself plus the apportioned cost of all fuel delivery logistics and related force protection required beyond the Defense Energy Support Center (DESC) point of sale to ensure refueling of the system" (Defense Acquisition University [DAU], 2009). These two definitions are generally accepted by DoD. FBCF estimates the total cost of procuring and transporting fuel, infrastructure operating costs, and the cost of force protection for the logistics tail. Although the definition of FBCF is not consistent across the DoD, the underlying principles are agreed on and understood among each branch of service (Hills, 2011).

FBCF is a useful guide for decision makers to make more realistic analysis on which systems or platforms should be purchased. The circumstances and the location in which the fuel is used can change FBCF, and decision makers can use this information while determining where to place particular systems or platforms.

The system developed by Office of the Undersecretary of Defense for Acquisition, Technology and Logistics (OUSD (AT&L)) for DoD programs to calculate the FBCF can be seen in Figure 4.

Element	Burden Description
Commodity Cost of Fuel	DESC standard price for the appropriate type or types of fuel
Primary Fuel Delivery Asset O&S Cost*	Cost of operating service-owned fuel delivery assets including the cost of military and civilian personnel dedicated to the fuel mission.
Depreciation Cost of Primary Fuel Delivery Assets*	Measures the decline in value of fuel delivery assets with finite service lives using straight-line depreciation over total service life
Direct Fuel Infrastructure O&S and Recapitalization Cost*	Cost of fuel infrastructure that is not operated by DESC and directly tied to energy delivery
Indirect Fuel Infrastructure*	Cost of base infrastructure that is shared proportionally among all base tenants
Environmental Cost*	Cost representing carbon trading credit prices, hazardous waste control and related subjects.
Other Service & Platform Delivery Specific Costs*	Includes potential cost associated with delivering fuel such as convoy escort, force protection, regulatory compliance, contracting and other costs as appropriate.

* These costs vary by Service and delivery method (ground, sea, air)

Figure 4. The seven cost elements used by OUSD (AT&L) for estimating FBCF (from DAU, 2009)

C. INPUT-OUTPUT MODEL

In the 1930s Professor Wassily W. Leontief, creator of the Leontief Input-Output (IO) analysis, started to develop his model to analyze the relationships between industries in an economy. These industries have interdependencies, and in order to produce its output, each industry needs to consume some output from the other industries and some of its own output as well. For example, the petroleum refining industry will need to use some amount of its own output, refined fuel, as well as other industries' outputs, like

electricity and machines, to be able to continue production. Any sector's total domestic production is equal to the sector's products used by all sectors in the economy as an input to produce their output, plus the amount demanded for final use by consumers, exports, investments, and government (Wu and Chen, 1990).

Since a typical economy can have a large number of industries and relationships, and interdependencies between these industries can be very complicated, some assumptions need to be made to simplify the system:

- Each industry produces only one homogenous commodity.
- For the production of its output each industry uses a fixed input output ratio.
- Each industry's production is subject to a constant return to scale.

Leontief developed an economic model for the United States economy in 1949. He divided the economy into 500 sectors and used matrices to describe the interdependencies between sectors. These matrices consist of linear equations developed for each industry. Each linear equation indicates how much the sectors in the economy use that sector's output.

1. Closed Leontief Model

There are two kinds of Leontief IO Models in terms of outside demand. In the Closed Leontief Model, no kind of outside demand can be met or no kind of outside demand exists. Every output that is produced by the industries of the economy is consumed by the economy itself. Since there is no interaction with the outside, this model can be used to find the production level for each industry which is needed to satisfy the internal demand within the economy.

2. Open Leontief Model

In the Open Leontief Model there is an external demand for the outputs of the industries in the economy. The industries of the economy do not consume all the products and an external demand can be met by the economy. Since there is an external demand to be met, this model can be used to find the production level for each industry which is needed to satisfy both internal and external demands.

In the Open Leontief Model, it is assumed that the economy has *n* industries and there are both internal and external demands on each industry. Internal demand is the demand placed on the industry by the other industries in the economy, and external demand is the demand placed on the industry from outside the economy.

In the Open Leontief Model x_i denotes the *i*th industry's total production, e_i denotes the external demand on the *i*th industry, and a_{ij} denotes the *j*th industry's internal demand on the *i*th industry. Furthermore, a_{ij} is the required number of units of industry *i*'s output to produce one unit of the output of industry *j*. Thus, $a_{ij}x_j$ is the total amount industry *j* demands from industry *i*. If we assume that the total demand is equal to the total output of each industry we have the following linear system:

$$\begin{pmatrix} a_{11}x_1 + a_{12}x_2 + & \dots & a_{1n}x_n + e_1 = x_1 \\ a_{21}x_1 + a_{22}x_2 + & \cdots & a_{2n}x_n + e_2 = x_n \\ \vdots & & \vdots \\ a_{n1}x_1 + a_{n2}x_2 + & \cdots & a_{nn}x_n + e_n = x_n \end{pmatrix}$$

Table 1. The open Leontief model matrix

From this matrix, total production for the *i*th industry is:

$$x_i = a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n + e_i$$

where x_i is the total output level of the ith industry to meet the demands of other *n* industries in the economy and the external demand (e_i).

D. PREVIOUS STUDIES

Corley (2009) analyzed the effects of FBCF on analysis and decisions Navy Major Defense Acquisition Programs made. To understand how FBCF affects the calculations, Corley used the FBCF calculator developed by the OUS (AT&L) to calculate the FBCF consumed by a standard Navy destroyer in different environments. His findings showed that between 50% and 70% of the FBCF is nonfuel cost, and between 30% and 50% of the FBCF is actual fuel cost and can be explained by the fuel

price set by Defense Logistics Agency Energy. He recommended using FBCF to determine fuel costs during the acquisition process.

Truckenbrod (2010) made a study to find how the FBCF could be applied to Navy aircraft. Truckenbrod also used the OUSD (AT&L) calculator to calculate the FBCF for an F/A-18 E/F aircraft just as Corley (2009) did for the standard Navy destroyer. Results of his study showed that FBCF for the aircraft was twice as much as for the destroyer. Truckenbrod concluded that main factor for this large difference between two FBCFs was aerial refueling. Truckenbrod recommended modifying current aircraft to extend their endurance and continue looking for technologies for saving fuel.

In another study, Roscoe (2010) analyzed the FBCF calculation methodologies used by the military services and found differences in how each service was calculating FBCF. The United States Navy (USN) and United States Marine Corps (USMC) are using a process developed by OUSD (AT&L), the Air Force created its own calculation, and the Army is still developing its process. Roscoe made a comparison between OUSD (AT&L) models and the one used by the Air Force and ran each model through several scenarios. There was no statistical difference between the results of the two models. Thus, Roscoe (2010) made three recommendations:

- The definition for the FBCF should be uniform across the services.
- The use of scenarios should be maintained when calculating the FBCF during analysis of alternatives (AOAs).
- Due to the unpredictability of real world scenarios, a stochastic process should be incorporated into FBCF calculations.

Larson and Witt (2013) used Monte Carlo simulation in a stochastic approach to develop an operational model for estimating the Fully Burdened Cost of Energy (FBCE) for the USMC. Three different scenarios were analyzed, and FBCE was calculated based on specific scenarios for a given system. As a result of their study Larson and Witt calculated the assured delivery price of fuel for USMC systems between $16.22 and $19.87 per gallon.

E. RESEARCH OBJECTIVE

Many studies are being conducted to estimate the real FBCF for DoD systems and platforms. In these studies FBCF for various vehicles and systems were calculated in various operating environments through multiple scenarios. Previous works analyzed the effects of different fuel transportation methods, such as sea delivery, air delivery, and ground delivery. However none of the previous studies takes into account the fact that an increase in the gross weight of a vehicle results in an increase in its fuel consumption. Furthermore, no previous SSSC models include demand at intermediate nodes while calculating the FBCF.

This study has two objectives. The first objective is to analyze the effects of a change in vehicle fuel consumption rates on fully burdened cost of supplies in an SSSC. The second objective is to find out how the existence of demand at intermediate nodes affects the fully burdened cost of supplies.

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II. METHODOLOGY

A. ASSUMPTIONS

Estimating and calculating the FBCF in SSSC requires lots of information and data. During our research we were not able to find all the information needed to run our Excel model. So we had to make several assumptions. The assumptions we made are:

- Increasing the gross weight at which a vehicle operates will increase its fuel consumption (Coyle, 2007). In the study made for The Department for Transport of United Kingdom, the relationship between payload and fuel consumption is explained and modeled using linear regression. (Figure 5 depicts the regression lines of the tipper vehicles.) As it is shown in Table 2, it is found that the miles per gallon (mpg) rate of 26, 32, and 44 ton trucks decreased respectively from 14.14, 12.24, and 10.27 to 7.96, 6.40, and 5.51 when they are fully loaded. The mpg factors of the vehicles, which are the ratio of mpg when the vehicles are fully loaded to the mpg when same vehicles are empty, are 0.56, 0.52, and 0.54. For the sake of this project we assumed that our vehicles' mpg factor is 0.55 when they are fully loaded. In the scenarios there are four nodes in the supply chain. In two of the scenarios trucks unload one third of their payload. Since there are three stages and vehicles will unload the same amount in every stage, we increased the mpg factor in every stage by 0.15 (1 - 0.55 = 0.45 / 3 = 0.15).

	MPG		**MPG FACTOR**
VEHICLE	**EMPTY**	**FULLY LOADED**	**FULLY LOADED / EMPTY**
44 TONNES TRUCK	**10.27**	**5.51**	**0.54**
32 TONNES TRUCK	**12.24**	**6.40**	**0.52**
26 TONNES TRUCK	**14.14**	**7.96**	**0.56**

Table 2. Mpg and mpg factors of vehicles

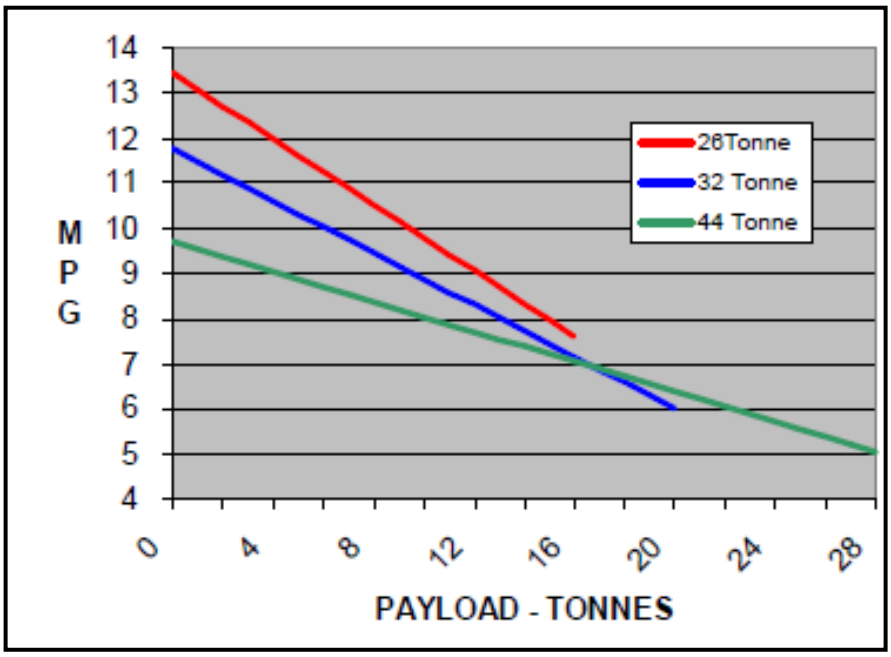

Figure 5. Regression lines of Tipper vehicles (from Coyle, 2007)

- Fuel consumption rates of vehicles given in the U.S Marine Corps Technical Manual, Principal Technical Characteristics of U.S Marine Corps Motor Transportation Equipment, TM 11240-OD are the fuel consumption rate of empty vehicles.
- Force Protection vehicles are fully loaded during the convoy as they only transport force protection personnel and these vehicles will not unload any payload.
- Vehicles and personnel on the convoy consume only fuel. Meal Ready to Eat (MRE) and water consumption of the convoys are ignored.
- Labor cost for personnel, consumptions in the bases and nodes are ignored.
- The cost of fuel is $17 per gallon at the start of the supply chain.
- Cost of an MRE is $5 per pack at the start of the supply chain.
- In their study to determine the Fully Burdened Cost of Water for a ground convoy in Afghanistan Blankenship and Cole (2009) calculated the assured delivery price of water between $4.60 and $4.90. We used $4.75 per gallon at the start of the supply chain.

- In the U.S.M.C. Force Order 10110.1A it is stated that one box of MRE weighs 22 lbs. and each box contains 12 MREs. From the information given one MRE weighs 1.83 lbs.
- Weight of 1 gallon of fuel is 6 lbs. and weight of 1 gallon of water is 8 lbs.
- Convoys between each node are composed of two force protection vehicles and two cargo trucks.
- For the purpose of this study Operating and Support costs are ignored.
- Average speed of the convoys is 30 mph.

B. NOTATION

The Fully Burdened Cost of Supply (FBCS) model presented in this section is an extension of Regnier et al. (2013). The model examines one individual path through the logistics network. Let this path have n nodes. The stage which begins at node i and ends at node $i+1$ is referred to as stage i; the path has $n-1$ stages. It is assumed that there are m different commodities transported on it, indexed by c. It is also assumed that all commodities can be expressed in the same units, whether by weight or volume. The model includes the following parameters:

x_n^c - amount of commodity c needed at the destination (exogenously given requirement)

x_i^c - amount of commodity c required at node i

X_i - total requirement at node i. Note $X_i = \sum_{c=1}^{m} x_i^c$

d_i - distance of stage i, i.e. from node i+1

r_i^c - amount of commodity c consumed per unit distance on stage i

R_i - total consumption per unit distance on stage i. Note $R_i = \sum_{c=1}^{m} r_i^c$

α_i - number of personnel required on convoy in stage i

β_i - average speed on stage i (includes time spent loading and unloading)

w_i - total convoy capacity on stage i, including payload plus internal fuel tanks

The values of these parameters will depend on the particular logistics network being analyzed. Many of the parameters are easily obtainable given a familiarity with the network.

K_i - number of convoy round trips required in stage i.

$$K_i \approx \frac{X_{i+1}}{w_i - 2d_i R_i}$$

This expression is an approximation because fractional round trips are impossible; the size of the error is trivial if the number of round trips is large. The model allows for replenishment of logistics assets within a stage—the distance of a stage is not constrained by the internal fuel tank of a transportation asset, for example.

L_i - number of labor hours required per convoy round trip on stage i.

$$L_i = \alpha_i \frac{2d_i}{\beta_i}$$

Requirements for each commodity at each node:

$$x_i^c = x_{i+1}^c + 2K_i d_i r_i^c + a_i^c L_i K_i$$

Total FBCS for a path through the supply network:

$$\sum_{c=1}^{m} x_1^c y_c + 2\sum_{i=1}^{n-1} d_i \phi_i K_i + y_L \sum_{i=1}^{n-1} L_i K_i$$

Λ_i - stage multiplier

$$\Lambda_i = 1 + \frac{2d_i R_i + L_i A_i}{w_i - 2d_i R_i}$$

The stage multiplier shows the increase in the total requirement at node i per unit of increase in total requirement at node $i+1$.

For the purposes of this project:

- K_i is manually fixed to 0.5 round trips in scenarios 1 and 3,
- the amount of commodity consumed at nodes per hour of labor on stages, total consumption at nodes per hour of labor on stages, operating and support cost per unit of distance for the convoy on stages (vehicle depreciation, maintenance costs and any similar costs not explicitly captured in consumption), unit cost of purchasing/producing commodities at the start of the supply chain, and the cost of labor are assumed 0,
- all the commodities are expressed by weight.

The demands of intermediate nodes for each commodity are added manually to x_i^c .

C. MULTIPLIER EFFECT

By using the Input-Output model, it is likely to estimate the effects of changes in demand at one stage according to the demands of other stages. The concept of multiplier effect is used frequently in this effort. In his thesis, Dubbs (2011) stated that a one-gallon increase in fuel usage by the end user does not translate to a one-gallon increase in total demand for fuel entering the supply chain, but increases the total fuel demand by a factor greater than one.

If the warfighter requires *X* gallons of fuel, some proportion of *X* is consumed by the preceding stage of the network, and thus some larger amount $X + \Delta$ is required at the start of this stage. The stage preceding that one will, in turn, consume some proportion of $X + \Delta$, resulting in an even larger requirement. This process continues all the way back to the beginning of the network, where the fuel requirement may be substantially greater than X gallons, depending on the characteristics of the network (Regnier et al, 2013).

For our scenarios which will be explained in the following part of this study, we used a model developed by Regnier et al (2013). The model calculates the multiplier effect itself. Since the consumption of MRE and water is ignored during delivery, the model computes the multiplier effect based on fuel. Figure 6 depicts the multiplier effect for Scenario 3.

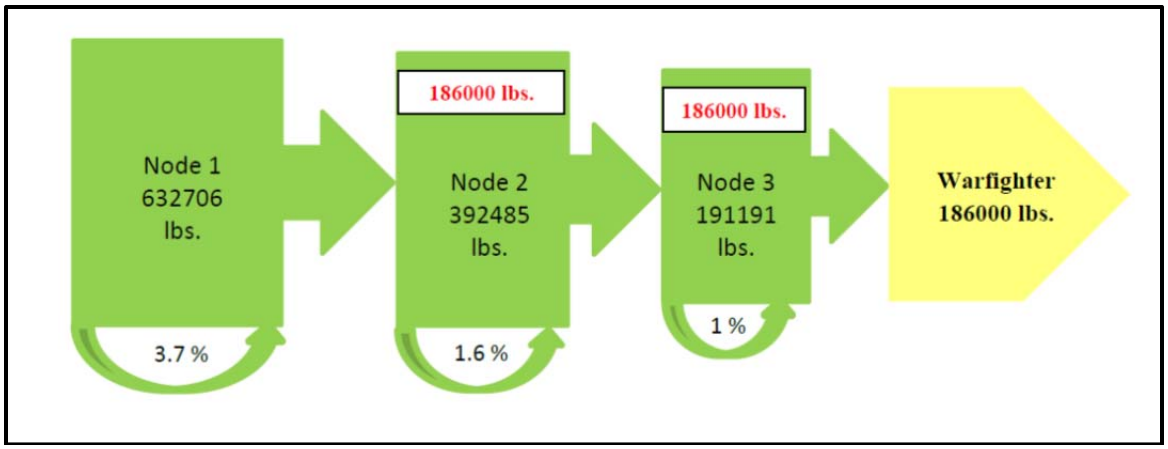

Figure 6. Multiplier effect of multiple commodities

D. SCENARIOS

To be able to see the effect of fuel consumption rates of vehicles when they are fully loaded or empty and the effect of carrying commodities among the multi-stage nodes, it is beneficial to use scenarios. In our project, we analyze five different scenarios. In the first two scenarios, we assumed constant fuel consumption rate. In the third and fourth scenarios, we calculate the fuel consumption rates of vehicles and make our analysis according to these results. In the last scenario, we disregard the need for the intermediate nodes, and we assume that there is only demand in the last node.

In our base scenario, there is one main operating base (MOB) and three additional bases. The MOB is consuming fuel, but it also serves the role of supplier to other bases. The other bases are just consuming fuel, MRE, and water, and do not have any supply capabilities. According to our base scenario, Kandahar is the MOB, and the other three bases are Camp Leatherneck, Deleram and Geiger. A map and distance between the MOB and other bases are shown in Figure 7.

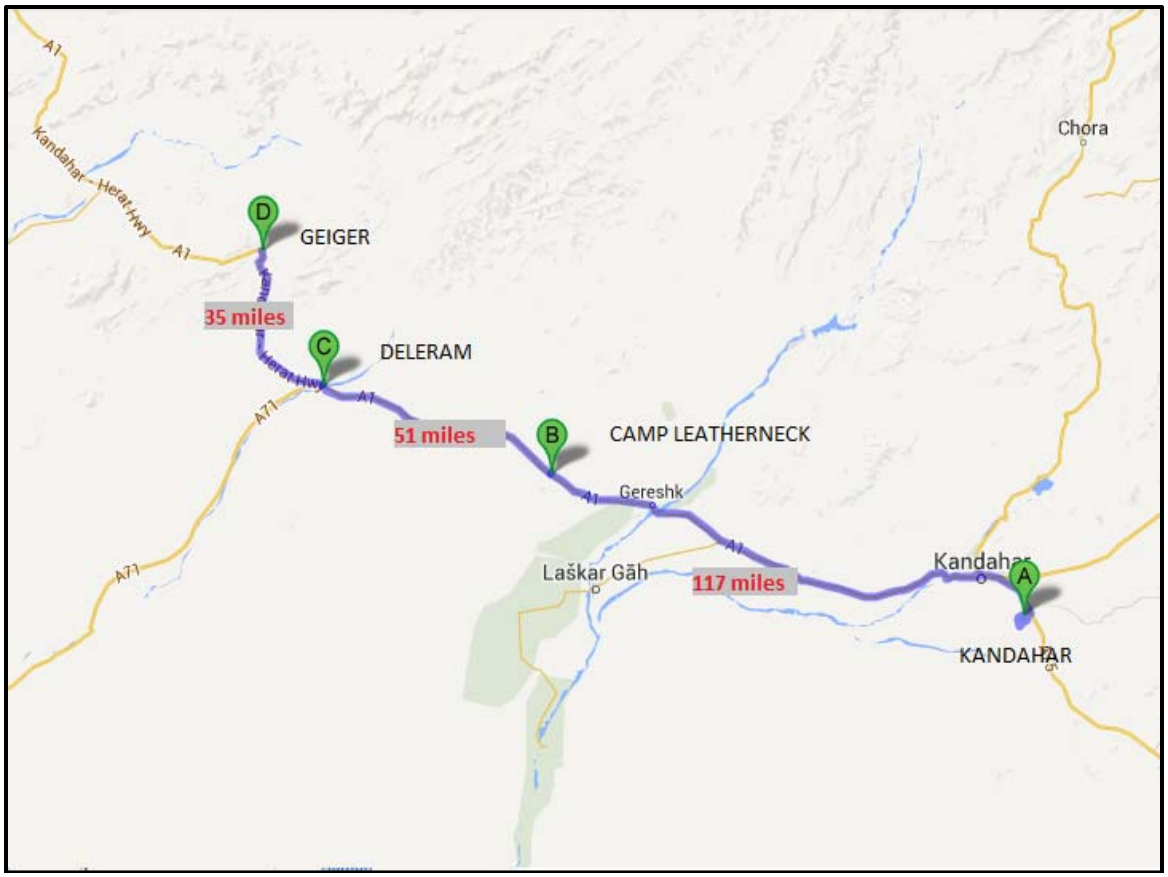

Figure 7. Map of the supply chain nodes in Afghanistan

1. Vehicles

We used ground transportation and two different types of convoys. In both small and big convoys, we used force protection vehicles and cargo trucks. The features of the vehicles are described in the following paragraphs:

a. Force Protection

The FPII CAT II A1 Mine Resistant Ambush Protection (MRAP) vehicles are designed to conduct logistics operations, including convoy security, troop and cargo transportation, and medical evacuation while allowing for enhanced maneuverability in all-terrain environments. The MRAP's cab capacity is one driver plus nine passengers. The fuel tank capacity of the MRAP is 100 gallons, and its fuel consumption is 5 mpg. Figure 8 depicts the USMC MRAP.

Figure 8. Mine-resistant, ambush-protected vehicle, CAT II A1, ISS, COUGAR, 6X6

The MRAP All-Terrain Vehicle (M-ATV) was designed to meet emerging theater requirements. The M-ATV provides better overall mobility characteristics than the original MRAP variants, while providing better survivability characteristics than any variant High Mobility Multipurpose Wheeled Vehicle. The M-ATV provides small unit combat operations in complex and highly restricted rural, mountainous, and urban terrain. It supports mounted patrols, reconnaissance, security, convoy protection, casualty evacuation, data interchange, and command and control functions. The M-ATV's cab capacity is one driver plus four passengers. Fuel tank capacity of the MRAP is 40 gallons, and its fuel consumption is 6.6 mpg. Figure 9 depicts the USMC M-ATV.

Figure 9. Mine-resistant, ambush-protected, all-terrain vehicle 11803A (M-ATV)

b. Cargo Trucks

The AMK27 is the MK27/MK27A1 with non-reducible MTVR Armor System (MAS) installed. The AMK27A1 is the MK27/MK27A1 with reducible MAS installed. The AMK27A1 also features an extra-long wheel base. The MAS kits provide complete 360-degree protection as well as overhead and underbody protection for the crew compartment. The troop seat kit allows for 20 passengers in the cargo bed. AMK27's cab capacity is one driver plus two passengers. Fuel tank capacity of AMK27 is 80 gallons, its fuel consumption is 4.5 mpg, and its towed load is 22,000 lbs. Figure 10 depicts the USMC AMK27.

Figure 10. Truck, cargo, 7-ton, armored, AMK27

The AMK23 is the MK23/MK23A1 with non-reducible MAS installed. The AMK23A1 is the MK23/MK23A1 with reducible MAS installed. The kits provide complete 360-degree protection as well as overhead and underbody protection for the crew compartment. The Armored Troop Carrier that seats 16 is available as an option for either variant; also the troop seat kit allows for 16 passengers in the cargo bed. The AMK23's cab capacity is one driver plus two passengers. Fuel tank capacity of AMK23 is 80 gallons, its fuel consumption is 4.5 mpg, and its towed load is 22,000 lbs. Figure 11 depicts the USMC AMK23.

Figure 11. Truck, cargo, 7-ton, armored, AMK23

The images and technical information about the vehicles are taken from the *Principal Technical Characteristics of U.S. Marine Corps Motor Transportation Equipment Technical Manual*, TM 11240-OD.

2. Scenario 1: Three Small Convoys (Constant Fuel Consumption Rate)

In Scenario 1, the convoys consist of two force protection vehicles and two cargo trucks. Each node has its own vehicles. In stage one, the convoy between Kandahar and Camp Leatherneck transports the commodities needed in Camp Leatherneck, Deleram, and Geiger to Camp Leatherneck. The vehicles move from Kandahar to Camp Leatherneck fully-loaded and return empty. In stage two, the convoy between Camp Leatherneck and Deleram transports the commodities needed in Deleram and Geiger to Deleram. The vehicles move from Camp Leatherneck to Deleram fully-loaded and return empty. In stage three, the convoy between Deleram and Geiger transports the

commodities needed in Geiger to Geiger. The vehicles move from Delaram to Geiger fully-loaded and return empty. To satisfy all the demands of the three nodes, the convoys can make multiple round trips. During the delivery, the convoy transports needed all three commodities (fuel, MRE, and water) for the other bases. Demand for each commodity at each node is same. In this scenario, the difference between the fuel consumption rate of fully-loaded and empty vehicles is disregarded and the fuel consumption rate is calculated according to the information given in the U.S. Marine Corps Technical Manual.

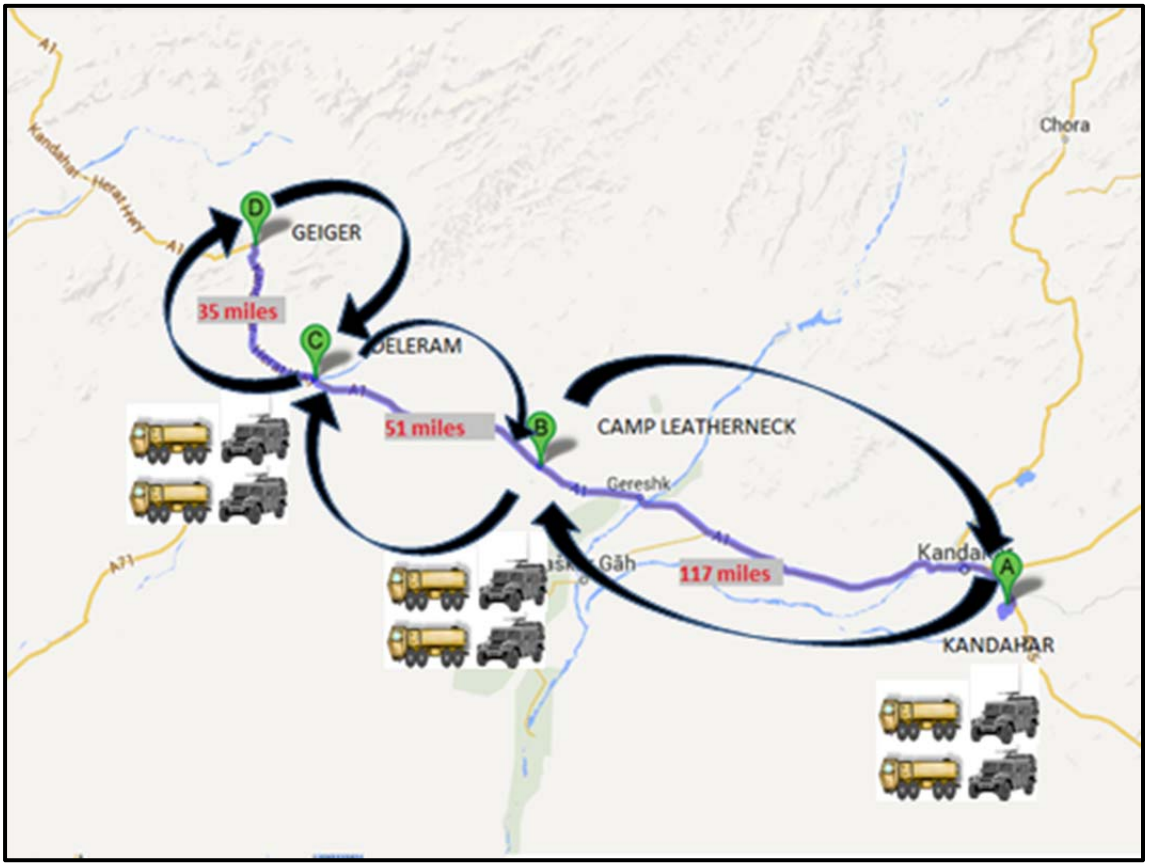

Figure 12. Three small convoys (constant fuel consumption rate)

3. Scenario 2: One Big Convoy (Constant Fuel Consumption Rate)

In Scenario 2, the convoy consists of 12 vehicles, 6 force protection vehicles, and 6 cargo trucks, which are located in MOB Kandahar, and there are no supply vehicles in

the bases. This convoy is the only one to satisfy all the needs of bases in the supply chain. The convoy moves from Kandahar fully-loaded and unloads one third of its payload at each node and returns to Kandahar. To satisfy the all the demands of the three nodes, the convoys can make multiple round trips. During the delivery, the convoy transports needed all three commodities (fuel, MRE, and Water) for the bases. Demand for each commodity at each node is same. In this scenario, the difference between the fuel consumption rate of fully-loaded and empty vehicles is disregarded and the fuel consumption rate is calculated according to the information given in the U.S. Marine Corps Technical Manual.

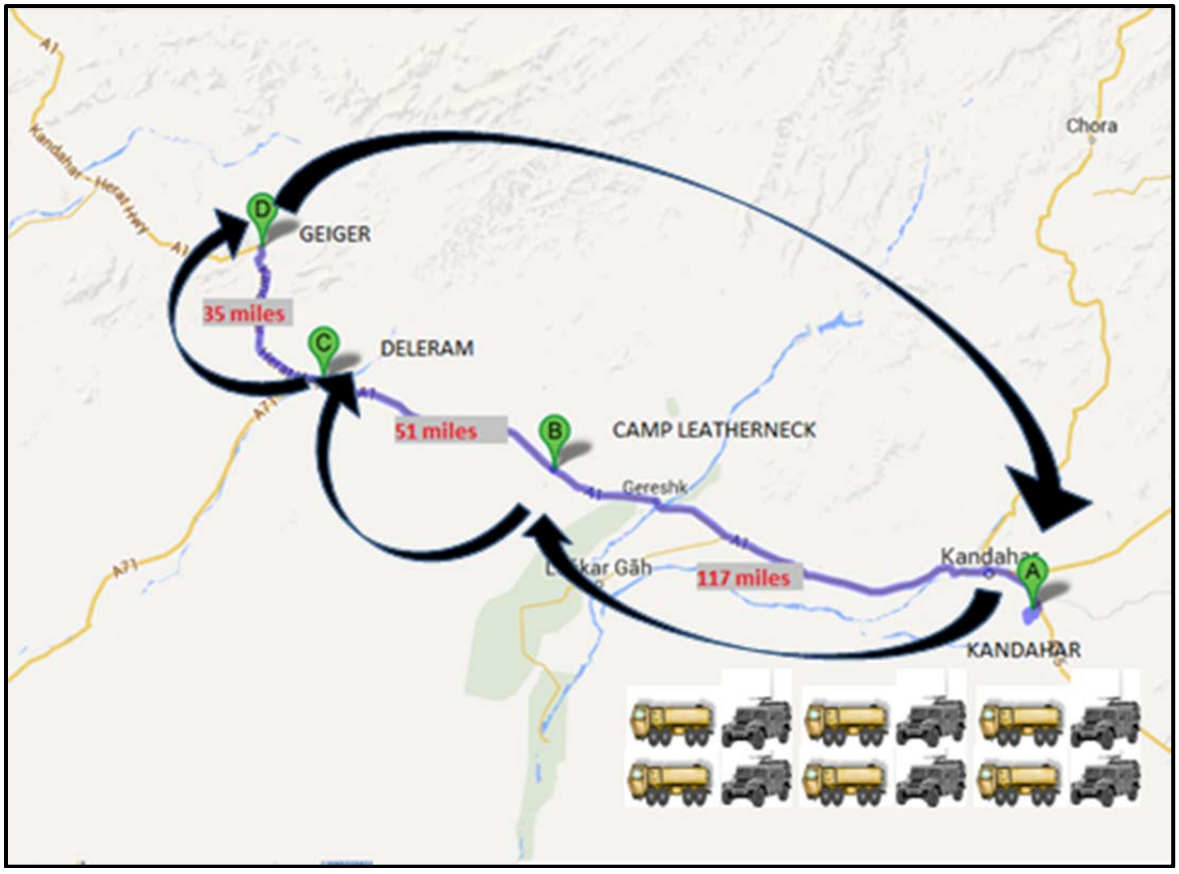

Figure 13. One big convoy (constant fuel consumption rate)

4. Scenario 3: Three Small Convoys (Different Fuel Consumption Rate)

The composition of the convoys and delivery system are the same as in Scenario 1. In this scenario, we use different fuel consumption rates for fully-loaded and empty vehicles. We use 0.55 as the mpg factor for fully-loaded vehicles and 1.00 for empty vehicles. Force protection vehicles are assumed to be fully loaded during the convoy since they only transport force protection personnel, and these vehicles will not unload any payload.

5. Scenario 4: One Big Convoy (Different Fuel Consumption Rate)

The composition of the convoys and delivery system are the same as in Scenario 2. In this scenario, we use different fuel consumption rates for fully-loaded and empty vehicles. We use the mpg factor of 0.55 for fully loaded vehicles and 1.00 for empty vehicles. In stage one, since the vehicles are fully loaded, we use 0.55 as the mpg factor. Vehicles unload one-third of their payload in Camp Leatherneck and continue to Deleram with two-thirds of their payload. So for stage two, we increase the mpg factor from 0.55 to 0.70. In stage three, we use 0.85 as the mpg factor.

6. Scenario 5: Three Small Convoys (Different Fuel Consumption Rate-Delivery Only For Last Node)

The composition of the convoys and delivery system are the same as in Scenario 3. Also in this scenario, we use different fuel consumption rates for fully-loaded and empty vehicles. We use 0.55 as the mpg factor for fully loaded vehicles and 1.00 for empty vehicles. Force protection vehicles are assumed to be fully loaded during the convoy since they only transport force protection personnel, and these vehicles will not unload any payload. In this scenario, there is no demand at the intermediate nodes (Camp Leatherneck and Deleram).

III. ANALYSIS AND FINDINGS

Earlier studies related with fully burdened cost only focused on the cost of fuel. Some studies described the cost elements of FBCF, and other projects researched the cost of the fuel until it reached the operation area. There are recent studies on multiple commodities. Regnier et al. (2013) have recently studied multi-commodities and developed a model which calculates the fully burdened cost of supply needed in the last stage. However, none of those studies covered the need of intermediate nodes. Also the fuel consumption of fully-loaded and empty vehicles was not taken into consideration either. Previous studies approached the issue from the macro level, but our study is in smaller scale and covers operational territory.

This project analyzes the effects of demand at intermediate nodes and different fuel consumption rates of fully-loaded and empty vehicles on the unit cost of commodities. Furthermore, the analysis of the fuel consumption of vehicles when they are fully loaded and empty enabled us to compare these results with calculations based on single consumption rate. We developed different scenarios and used an Excel spreadsheet for computing consumption in SSSC to get comparable results. In the scenarios, we made changes to the size of the convoy and delivery system. The need of the nodes and convoy capacity are fixed to make an accurate analysis. In calculations, the capacity of the convoys is 49,000 lbs. in small convoys and 147,000 lbs. in big convoys, and the amount of commodities needed at all three nodes is shown in Table 3.

Stages	Distance (miles)	Fuel		MRE		Water	
		gallons	weight (lbs.)	#	weight (lbs.)	gallons	weight (lbs.)
Kandahar - Camp Leatherneck	117	31,000	186,000	26,000	47,580	30,000	240,000
Camp Leatherneck - Deleram	51	31,000	186,000	26,000	47,580	30,000	240,000
Deleram - Geiger	35	31,000	186,000	26,000	47,580	30,000	240,000
Total	**203**	**93,000**	**558,000**	**78,000**	**142,740**	**90,000**	**720,000**

Table 3. Amount of resources needed at each node

A. FINDINGS

1. Fuel Consumption and Number of Round Trips

In Scenario 1 and Scenario 2 different fuel consumption rates of fully-loaded and empty vehicles were ignored, and calculations were made based on the information given in the previously cited technical manual. In Scenario 1, convoys make 30 rounds trips in stage 1, 20 round trips in stage 2, and 10 round trips in stage 3. In total, the convoy consumed 7,709 gallons of fuel. Distribution of convoy fuel consumption among the stages of Scenario 1 can be seen in Figure 14.

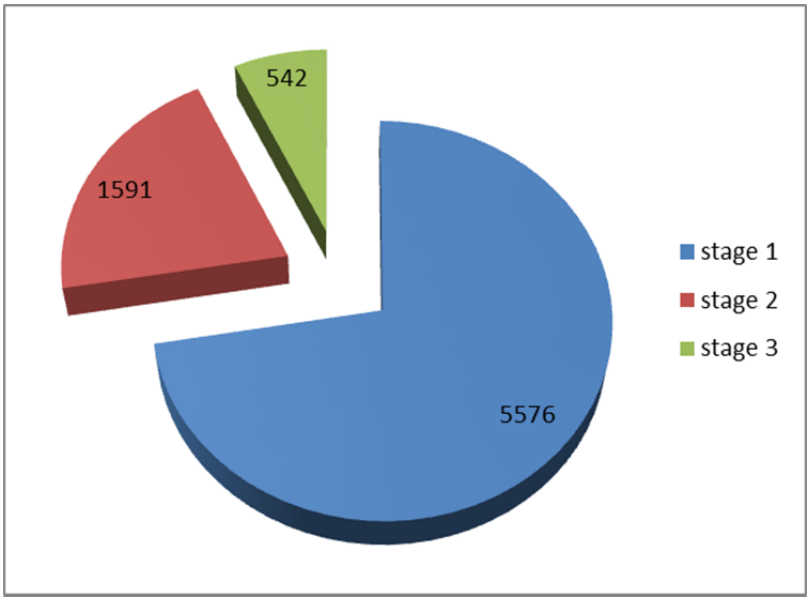

Figure 14. Distribution of fuel consumption in Scenario 1

In Scenario 2 one big convoy moved from the MOB and unloaded one-third of its payload at each node and returned to the MOB empty. In order to satisfy the demand at each node this convoy made 10 round trips. In total, the convoy consumed 9,695 gallons of fuel. Distribution of convoy fuel consumption among the stages of Scenario 2 can be seen in Figure 15.

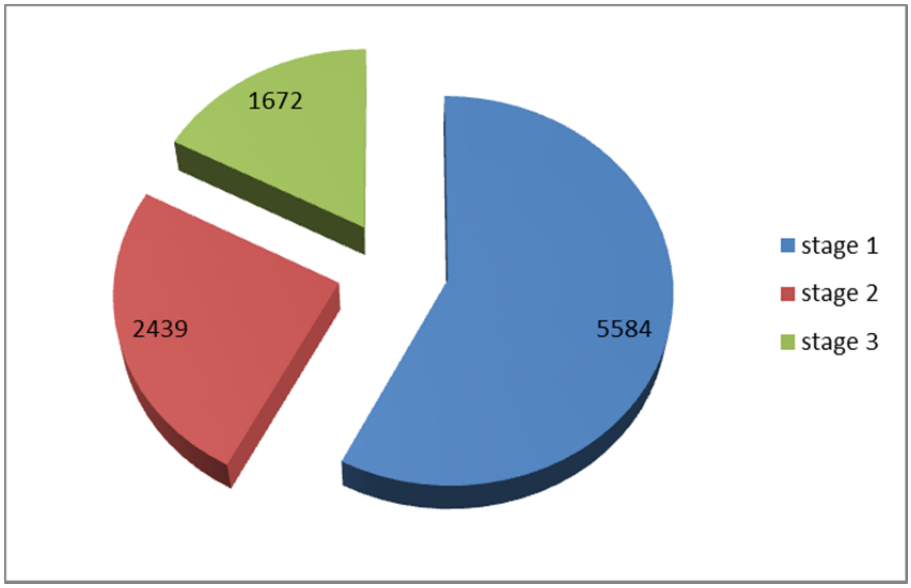

Figure 15. Distribution of fuel consumption in Scenario 2

In Scenario 3 and Scenario 4 we used the same convoy composition as those for Scenario 1 and Scenario 2. Using different fuel consumption rates for fully-loaded and empty vehicles significantly increased the total fuel consumption of the convoy. However, it did not make a considerable impact on the distribution of fuel consumption among the stages.

In Scenario 3, convoys made 31 rounds trips in stage 1, 20 round trips in stage 2, and 10 round trips in stage 3. In total convoys consumed 12,451 gallons of fuel. Distribution of convoy fuel consumption among the stages of Scenario 3 can be seen in Figure 16.

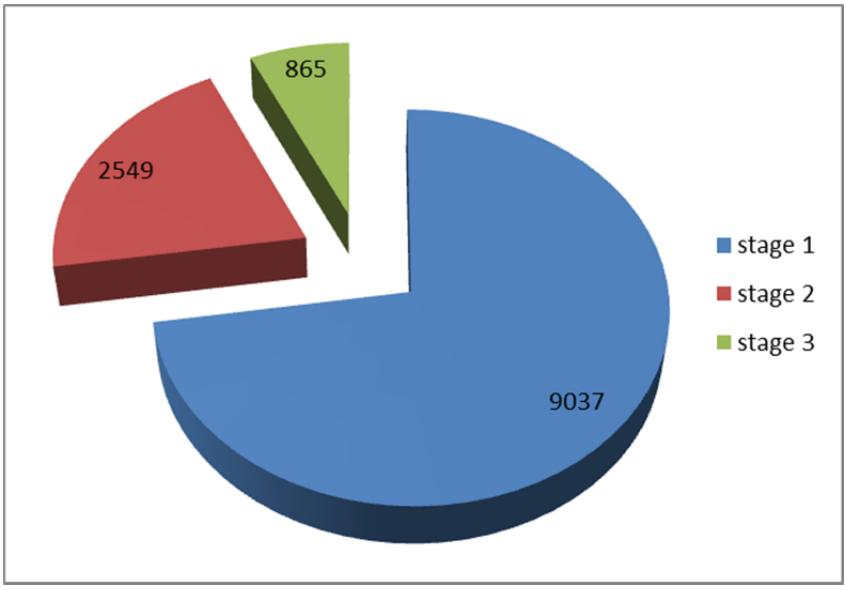

Figure 16. Distribution of fuel consumption in Scenario 3

In Scenario 4 one big convoy made 10 round trips. Since vehicles unloaded one-third of their payload in each stage, we used different fuel consumption rates for each stage. Fuel consumption rates of the vehicles decreased after partially unloading their payload. In total the convoy consumed 14,848 gallons of fuel. Distribution of convoy fuel consumption among the stages of Scenario 4 can be seen in Figure 17.

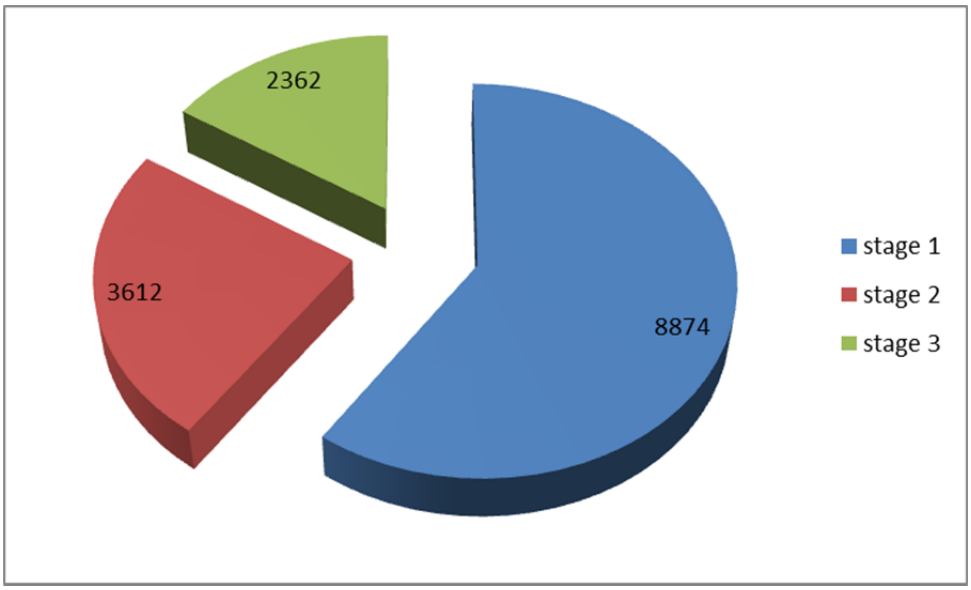

Figure 17. Distribution of fuel consumption in Scenario 4

In Scenario 5 we assumed that there is no demand at the intermediate nodes and the only demand is at node 3, the final destination of the convoy. We used this scenario to see how the absence of demands at intermediate nodes affects the total fuel consumption of the convoy and unit cost of commodities. In this scenario, convoys make 31 rounds trips in stage 1, 30 round trips in stage 2, and 30 round trips in stage 3. In total, the convoy consumed 15,591 gallons of fuel, which is the highest of all scenarios. Distribution of convoy fuel consumption among the stages of Scenario 5 can be seen in Figure 18.

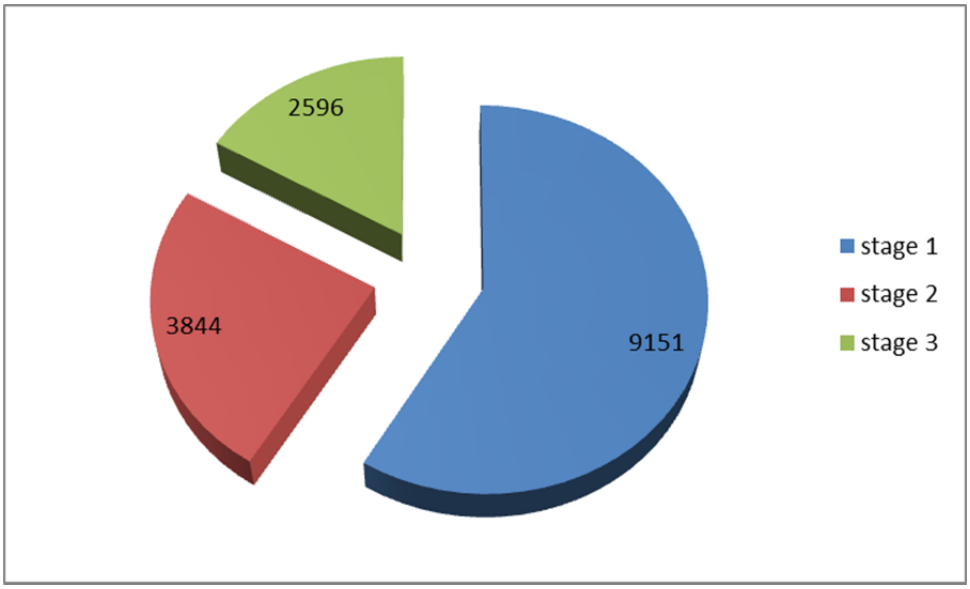

Figure 18. Distribution of fuel consumption in Scenario 5

a. Unit Costs of Commodities

Based on data collected from previous studies and our assumptions, we determined the per-unit cost of each commodity for the beginning of each scenario. After running the model through the scenarios we found new costs for the commodities using the total cost and weight of each commodity. Since we had to make many assumptions while producing scenarios, using the per-unit cost of commodities calculated in this project as a comparison tool between scenarios is more useful. The comparison of results can be found in the analysis section of this chapter.

B. ANALYSIS

Fuel consumption and total fuel cost can be seen in Table 4. Fuel cost is calculated based on the assumption that one gallon of fuel costs $17 at the MOB. There is a significant difference between using small convoys and big convoys. Keeping the convoy size small and making more round trips is more efficient than using big convoys and making a smaller number of round trips.

Scenarios	Fuel Consumption (gallons)	Fuel Cost ($)
1	7709	131,052.26
2	9695	164,811.39
3	12451	211,667.86
4	14848	252,415.00
5	15591	265,048.83

Table 4. Fuel consumption and fuel cost for each scenario

In Scenario 1 and Scenario 2 we used a constant fuel consumption rate for vehicles regardless of their payload. Results of our analysis showed that three small convoys making multiple round trips are more efficient than one big convoy making a smaller number of round trips. The big convoy in Scenario 2 consumes 26% more fuel than the three small convoys in Scenario 1.

In Scenario 3 and Scenario 4 different fuel consumption rates for fully-loaded and empty vehicles are used. After running the model for our scenarios we found that Scenario 3 is more efficient than Scenario 4. The fuel consumption in Scenario 4 is 19% more than that of Scenario 3. However, the difference between Scenario 1 and Scenario 2 is more than the difference between Scenario 3 and Scenario 4. We can explain this difference with the fact that the fuel consumption rate of a vehicle changes with the payload of the vehicle. In Scenario 3 the lowest mpg factor is used for fully-loaded

vehicles. In Scenario 4 vehicles were partially loaded between intermediate nodes and the mpg factor increased after each node. This application of using different mpg factors for partially-loaded vehicles created a larger difference between Scenario 1 and Scenario 3 than it created between Scenario 2 and scenario. The difference between Scenario 1 and Scenario 3 is 62%, and the difference between Scenario 2 and Scenario 4 is 53%.

Taking into account the fact that vehicle fuel consumption increases with the size of the payload, we can expect significant differences in the results between scenarios. The difference of 62% between Scenario 1 and Scenario 3 is considerably high. Since we could not find data about different fuel consumption rates for fully-loaded and empty vehicles, we made assumptions using Corley's (2007) study. Real information about this fact can help to get more realistic results for fuel consumption and FBCF.

In Scenario 5 we assumed there is no demand at the intermediate nodes and the whole demand of the supply chain is at node 3. We used the same convoy composition as in Scenario 3 since it was more efficient than the one in Scenario 4. This scenario gave us the opportunity to see the effects of the existence of demands at intermediate nodes. Since only node 3 has demand, vehicles did not unload any payload at the intermediate nodes and made a maximum number of round trips between all nodes. After running the model for Scenario 5 we saw that convoys in this scenario consumed the highest amount of fuel. The fuel consumption of Scenario 5 is 25% more than the fuel consumption of Scenario 3. The number of round trips made by the convoys in Scenario 3 and Scenario 5 are shown in Table 5.

Scenarios	Number of Roundtrips		
	Stage 1	Stage 2	Stage 3
3	31	20	10
5	31	30	30

Table 5. Number of round trips for scenarios 3 and 5

This change in the number of round trips increased the average distance the vehicles traveled and resulted in a significant increase in fuel consumption.

After running the model for 5 scenarios we calculated the total cost of commodities at the end of each scenario. Then we reflected the total cost on the cost of each commodity, and we found the results shown in Table 6.

Commodity	Unit	Beginning	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
		$	$	$	$	$	$
FUEL	1 Gallon	17.00	17.93	18.17	18.50	18.79	18.88
MRE	1 Pack	5.00	5.27	5.34	5.44	5.53	5.55
WATER	1 Gallon	4.75	5.01	5.08	5.17	5.25	5.27

Table 6. Cost of each commodity for each scenario

As seen in Table 7 the highest increase in cost of commodities is in Scenario 5.

SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
5.46%	6.87%	8.83%	10.52%	11.05%

Table 7. Total cost for each scenario as percentages

IV. CONCLUSION

In this project we used an Excel spreadsheet to estimate the FBCS in an SSSC. During our literature review and research we realized that no previous study focused on the existence of demand at intermediate nodes in an SSSC and how these demands at intermediate nodes affect the FBCS. We also did not see any FBCF study that takes into account the fact that vehicle fuel consumption rates change with their payload. Another important point that we wanted to shed light on was whether one big convoy that travels from the beginning of an SSSC to the end or small convoys traveling between each node was more efficient. We generated five scenarios to see the effects of different convoy compositions, different fuel consumption rates, and the existence of demand at intermediate nodes, and we obtained comparable results.

The first thing we examined was the effects of vehicle payload and different fuel consumption rates for fully-loaded and empty vehicles. It is clear that the fuel consumption rate of vehicles is one of the crucial factors that should be taken into consideration. Although there are many factors that affect the fuel consumption of vehicles, the payload is the most considerable one. Fuel consumption varies according to the vehicles' payloads. The more payload that the vehicles have, the more they consume fuel or vice versa. In Scenario 1, we used a constant fuel consumption rate for vehicles regardless of their payload, and in Scenario 3, we used the same convoy composition and delivery system as that of Scenario 1. We just changed the fuel consumption rate. We used 0.55 as the mpg factor when vehicles were empty and 1.00 as the mpg factor when they were fully loaded. The amount of fuel consumed was 7709 gallons in Scenario 1 and 12451 gallons in Scenario 3. This analysis shows that the convoy consumed 4742 gallons in Scenario 3 more than of the convoy in Scenario 1. Thus, approximately 38% more fuel was consumed. This ratio is not small enough to overlook. In our study, we approached the case on a smaller scale perspective and focused on the operation area. The distance between the first node at Kandahar and the last node at Geiger is 203 miles in all. However, in the case of bigger scale calculations, the difference in total fuel consumption in Scenario 1 and Scenario 3 will be higher.

Technical information related to vehicles was taken from the *Principal Technical Characteristics of U.S. Marine Corps Motor Transportation Equipment Technical Manual, TM 11240-OD* which covers the fuel consumption mpg and fuel consumption per hour. But it is not clear that this data pertains to fully-loaded vehicles or empty ones. In our study, since we do not have real data, we used the mpg factors according to our assumptions based on Corley's (2007) study. Real information can facilitate the accurate estimation of consumed fuel when the vehicles are fully loaded or empty. In order to be able to calculate FBCF and FBCS, different fuel consumption rates for fully-loaded and empty vehicles should be taken into consideration. A comprehensive study on fuel consumption rates of DoD vehicles can make a great contribution to FBCF and FBCS calculations within the DoD.

The acquisition system in the DoD is so comprehensive that it covers many aspects of commodities. All the technical and tactical features and criteria are taken into account during the acquisition process. Fuel efficiency is one of the essential criteria for the acquisition process of vehicles. Basically, the fuel consumption rates of vehicles are a good predictor of which vehicle is cost effective. However, fuel consumption mpg and fuel consumption per hour are not enough to decide which vehicle is more efficient. As stated previously, it is viable to make accurate evaluations by using the different fuel consumption rates of vehicles during the acquisition process.

Secondly, we tried to see which convoy composition was more efficient. We modified our scenarios to compare one big convoy going all the way from beginning to the end and small convoys making round trips between nodes. We kept the total number of vehicles in the SSSC constant, and our results showed that small convoys are more efficient than big convoys. The difference between the fuel consumption of Scenario 3 and Scenario 4 is around 19%. Instead of locating all the vehicles in the MOB and using big convoys to provide resources to the nodes, locating a small number of vehicles in each node and making multiple round trips between each node with smaller distances is more efficient. Commanders can use this information while determining the location of MOBs and other bases. The location of the bases can be determined in a way that makes it possible to situate vehicles in each node and to make multiple round trips between

nodes instead of one big convoy going through all the nodes. Of course the locations of these vehicles and bases are tactical decisions, and some other aspects of the theater can be more important than fuel efficiency of convoys, but our study suggests that this information should be taken into account while deciding where to locate bases, supply vehicles, and personnel.

The third effect we wanted to observe was how the existence of demand at the intermediate nodes affects the fuel consumption, FBCS, and unit price of commodities. In Scenario 5 we assumed that the only demand in the SSSC was at the last node. After running the model we found that fuel consumption of Scenario 5 was 25% more than the fuel consumption of Scenario 3, which has same convoy composition as Scenario 5. It is obvious that when the demand increases FBCS increases, regardless of the location of the demand. However, the existence of demand at the intermediate nodes decreased the average unit cost of commodities for each node. Since the distance between the MOB and the first node is smaller than distance between the MOB and second and third nodes, the average fuel consumption per node decreases when there is demand at earlier nodes. This information can be used to determine the location of MOBs and other bases.

We generated our scenarios based on multiple assumptions. The amount of commodity consumed at nodes per hour of labor in stages, total consumption at nodes per hour of labor in stages, operating and support cost per unit of distance for the convoy in stages (vehicle depreciation, maintenance costs, and any similar costs not explicitly captured in consumption), unit cost of purchasing/producing commodities at the start of the supply chain, and the cost of labor are assumed to be 0. In this study we only focused on three of the factors that can affect the fuel consumption of a convoy in an SSSC.

The results of our study can be summarized as:

- Using smaller convoys between each node is more efficient than using one big convoy which travels from the MOB and provides the resources to each node,
- Using different fuel consumption rates for fully-loaded and empty vehicles can generate more realistic FBCF and FBCS calculations, and having different fuel consumption rates for fully-loaded and empty vehicles is the key factor to make this calculation,
- Including demand at intermediate nodes decreases the unit cost of commodities that the SSSC provides to each node.

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